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THE EFFECTS OF VARIOUS "WARM-UP" PROCEDURES ON ACCELERATION, VELOCITY AND MUSCULAR ENDURANCE

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effects of Various "Warm-Up" Procedures on Acceleration, Velocity and Muscular Endurance," submitted by Robert W. Schutz in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of this study was to examine the effects of various intensities and durations of warm-up and the length of rest following warm-up on acceleration, velocity, and muscular endurance as measured by a twenty-five second sprint on a bicycle ergometer. The hypothesis was that there would exist a specific intensity and duration of warm-up which would be superior to any other warm-up and to the control situation. It was also hypothesized that there would be significant two factor interactions between all three independent variables. Sixty-six Edmonton boys, aged twelve to fourteen years, were tested, each one performing one type of warm-up on a treadmill before pedalling a bicycle ergometer for twenty-five seconds at maximum speed.

The results, as analyzed by analysis of covariance with weight as the covariate, showed that a preliminary rest period resulted in significantly greater acceleration, velocity, and muscular endurance than the average results of all the warm-up conditions. A warm-up at six miles per hour produced significantly better results in all three dependent variables than did one at four miles per hour. The length of warm-up, although not statistically significant, strongly suggested an optimal duration of six minutes over one or eleven minutes at a speed of six miles per hour but little difference at a speed of four miles per hour. The length of the rest period following warm-up had no effect on performance.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The concept that "warm-up" is beneficial to athletic performance has been accepted by most coaches, physical educators and physiologists since the time of Ancient Greek athletics, 2,600 years ago (39). Most athletic performers have their own warm-up rituals which they faithfully adhere to before each practice and competition in the belief that they will prevent injury or be advantageous to their subsequent performance.

Seaton (51:137) states that: "The physiological necessity of the warm-up is well known and accepted in athletics and physical education."

Gillett, a medical doctor, says (20:1117) "I am certain that a warm-up not only is helpful in bettering performance but, much more important, is essential in preventing injuries."

The conflicting results of a number of empirical findings in the last twenty years has caused a great deal of controversy to arise over the effects of warm-up on performance. Some studies have shown that warm-up increases speed of movement (1,12,47,62); some say it decreases speed (10); some authors say a related warm-up is most beneficial (12,62), and yet other investigators say an unrelated one enhances performance to the greater degree (47,54); some studies state that warm-up decreases muscle viscosity (1,18,36,40,48,56); some suggest increased neuromuscular facilitation (8,16,64); some say the major benefits are gained from increased circulation (12,40,46), and others suggest any benefits derived

from a warm-up are mainly psychologically induced (56).

It is quite possible that much of the confusion regarding the effects of warm-up on performance is due to the extreme variety in the types of warm-up used by the various investigators. For example: four laps around the gym at the subject's own pace (60), thirty minutes of bicycle pedalling at a work load of 660 kpm per minute (1), eight revolutions on a bicycle ergometer (55), twelve jumping jacks (55), thirty minutes of jogging and sprinting followed by fifteen minutes of rest and then ten minutes of light warm-up (64). In order to test the value of warm-up an investigator must not just look at one specific level and intensity, but must investigate the possible effects of a number of degrees and intensities of warm-up. Perhaps different types of warm-up are better for different sports; perhaps different durations and intensities act differently on different subjects. Perhaps age, environmental temperature and humidity, initial body temperature, sex, altitude and many other factors must be considered. Perhaps warm-up produces no beneficial effects at all.

In order to gain a better insight into the problem physical educators must approach it in a systemmatic manner. This can be accomplished if an investigator takes one small area and covers it thoroughly, then the next study can proceed logically from there. Because of the seemingly specific nature of warm-up, each investigation should delimit itself to a particular type of performance. The types of warm-ups could be such activities as "steady pace" running, "wind" sprints, specific practice, calisthenics or passive heating, but whatever it may be the investigator must thoroughly examine all aspects of it so that on completion of his

study he can state that this particular level and intensity of this type of warm-up resulted in optimal performance improvement.

Most athletic activities require speed of muscular contraction, some form or type of strength, accuracy, balance, coordination, concentration, reaction time, flexibility and endurance. It would seem advantageous for researchers to study the effects of warm-up on these components of performance rather than on specific skills as an entity themselves, with the assumption (questionable as it may be) that a beneficial effect on one or more of these factors would result in a similar performance improvement in all activities involving one or more of these particular components. Once the most favorable specific intensity and duration for each type of warm-up had been established for a particular component of physical performance, these optimal combinations could be compared with one another with the anticipated result being the discovery of the exact level, intensity and type of warm-up which will produce the most beneficial gains in performance for the component. The ultimate aim of this logical pattern of research is the evolvement of the most beneficial and efficient warm-up for every conceivable situation.

The components of performance which will be investigated in this study are acceleration, velocity and muscular endurance. These components are the basic ones involved in sprint running and are important in all types of athletic performance. If warm-up is actually a process of raising the body temperature, in particular the temperature of the working muscles, then the velocity of muscular contraction should increase thereby increasing the acceleration and velocity of the active limbs. These three dependent variables, acceleration, velocity and

muscular endurance will be measured by an "all-out" twenty-five second ride on a bicycle ergometer.

The Problem

The purpose of this study is to investigate the effects of a particular type of warm-up, namely, steady pace walking and running, on particular aspects of muscular endurance and the velocity of muscular contraction.

Subsidiary Problems

The subsidiary problems of this study are:

1. To determine the optimal intensity and duration of the warm-up activity as well as the most beneficial time interval between warm-up and athletic performance.

2. To investigate the interactions between intensity, duration and time lapse of warm-up.

3. To investigate the type and degree of trend of performance with increasing duration and time lapse.

Delimitations

Some of the delimitations of this study are:

1. The subjects used were sixty-six non-randomly chosen Boy Scouts and therefore inferences to a larger population are questionable.

2. The parameters studied are restricted to the specific dependent and independent variables chosen for this investigation. The statistical model is therefore a Fixed Effects Model and inferences cannot be made to other treatment conditions and performance criteria.

Limitations

The most severe limitations associated with the study are:

1. Psychological and motivational factors may increase the variability within groups, thereby overshadowing treatment differences.

2. The computation of the dependent variables from the recording paper necessitates some estimations and consequently error will be introduced into the results.

3. The reliability of the dependent variables is a limiting factor.

4. The temperature of the laboratory can be controlled only within a range of four to six degrees Farenheit, thus causing variation in the actual warming effect of the different warm-up conditions.

5. The dependent variable defined as muscular endurance is highly correlated with velocity and therefore may not be a good measure of muscular endurance as such.

6. The dependent variables of muscular endurance, acceleration and velocity are highly specific variables and therefore generalizations are restricted by the definitions of these variables as stated in this thesis.

Definition of Terms

Warm-up. Warm-up is used in the generally accepted manner, that is, a preliminary activity to performance, the purpose being to enhance the level of performance. Whether or not any parts of the body actually undergo an increase in temperature, although an important consideration, is not examined in this investiation and is not implied by the term warm-up.

<u>Related warm-up</u>. A related warm-up is one which involves the same general muscle area as will be used in the performance criterion, but is not actual practice.

<u>Practice warm-up</u>. Preliminary activities of exactly the same nature as the actual performance are defined as practice.

<u>Unrelated warm-up</u>. A warm-up which does not include solely the muscle area used in the performance activity is termed an unrelated warm-up. General calisthenics are classified in this category.

<u>Passive warm-up</u>. Passive warm-up is warm-up in which the subject exerts no effort nor applies any external force. The subject's muscles and/or body temperature is increased or decreased by external applications such as showers or short wave diathermy.

<u>Severe warm-up</u>. A severe warm-up is one which, by this investigator's subjective appraisal, would result in general or specific fatigue to the point of cessation of activity in approximately ten minutes or less. Because of the subjectiveness of the classification it is a rather flexible definition.

<u>Moderate warm-up</u>. A moderate warm-up is defined as a preliminary activity which elicits cardiovascular responses above and beyond those of such normal daily activities as standing and leisurely walking. It is a subjective evaluation by this investigator and therefore subject to considerable variation.

Acceleration. For the purposes of this study acceleration is defined as the time required to pedal four full revolutions on the bicycle after the completion of the first revolution.

Maximum velocity. The maximum number of pedal revolutions performed, calculated to the nearest one-hundredth of a revolution, in any one-second interval during the twenty-five second bicycle ride is defined as the maximum velocity.

Muscular endurance. Muscular endurance is operationally defined as the total number of revolutions performed in the twenty-five second ride. As velocity begins to decline after approximately ten seconds (13) this measure will be, to some degree, a measure of muscular fatigue but will obviously also include a component of velocity.

Intensity of warm-up. The intensity of a warm-up is a measure of the rate at which the activity is being performed. The greater the rate of movement, and force required for that movement, the greater the intensity. Moderate and severe warm-ups as previously defined are levels of the factor intensity.

Duration of warm-up. The duration of a warm-up is the actual period of time, measured in seconds, in which the preliminary activities were conducted.

Time lapse. Time lapse is the period of time from cessation of warm-up to commencement of the performance activity.

<u>Theoretical Hypothesis</u>

1. The intensity of warm-up will affect the performance variables acceleration, velocity and muscular endurance. The manner in which these variables are affected will depend on the duration of the warm-up and the length of the rest period following warm-up.

2. There exists a specific intensity, duration and time lapse which will produce optimal performance for a specific activity.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The number of studies conducted and reported in the literature involving various types of warm-up is quite extensive and yet one still cannot draw any valid conclusions as to the effects of warm-up on performance. The reason for this is the extreme diversity of the warm-up factors employed in the various studies thus making comparisons and summaries difficult and often meaningless. The varying factors which cause this difficulty are: the type of warm-up (related, practice, unrelated, or passive), the duration and intensity of the warm-up, the time lapse between warm-up and performance, the type of performance criterion (speed, endurance, strength, power, flexibility, accuracy, or general motor ability), the care taken in experimental methods and the adequacy of experimental controls. The most concise and comprehensive method of presenting and observing these factors is in the form of tables.

Tables I and II give a fairly detailed review of the studies reported involving the effects of warm-up on speed and endurance respectively. Because the effects of warm-up on other performance criteria are not being investigated in this study an analysis of studies using dependent variables other than speed and endurance has not been reported in detail. The type of warm-up as reported in these tables is based on the definition as stated in Chapter I of this thesis. The reported intensity of warm-up is also based on a previous definition and, due to the

TABLE I

SUMMARY OF STUDIES ON THE EFFECT OF WARM-UP ON SPEED OF MOVEMENT

Senior Author	Performance Criterion	Type of Warm-Up	Intensity	Duration	Time Lapse	Effect on Speed
Thompson (62)	Swimming	Related & passive heating	Moderate	2-3 min.	5 min.	Increased
		Unrelated	Moderate		5 min.	No effect
DeVries (12)	Swimming	Related	Moderate	8 min.	Immediate	Increased
		Passive heating		6 min.	Immediate	No effect
		Unrelated	Moderate		Immediate	No effect
		Massage		10 min.	Immediate	No effect
Muido (41)	Swimming	Passive heating	104^{o}-109^{o}F	18 min.	20 min.	Increased
		Unrelated	Moderate	10 min.		Increased
Carlile (9)	Swimming	Passive heating		8 min.		Increased
Asmussen (1)	Cycling	Practice	Moderate	30 min.		Increased
		Passive heating	117^{o}F	10 min.		Increased
		Massage		15 min.		No effect
Karpovich (32)	Cycling	Practice	Moderate	5 min.		No effect
Skubic (55)	Cycling	Practice	Very low	30 sec.	Immediate	No effect
		Unrelated	Low	30 sec.	Immediate	No effect
Smith (57)	Running	Related	Severe	2 min.		No effect
		Passive heating	110^{o}F	5 min.		No effect
Hipple (29)	Running	Practice	Severe	10 sec.	5 min.	No effect
Burke (8)	Spot Runn'g	Related	Moderate	2,5,8 min.	5 min.	No effect
		Related	Severe	2,5,8 min.	5 min.	No effect
Carlson (10)	Spot Runn'g	Practice	Severe	10 sec.	10 sec.	Decreased
Sills (54)	Spot Runn'g	Related	Low	5 min.		No effect
		Passive cooling	44^{o}-48^{o}F	8 min.		No effect
		Unrelated	Severe	10 min.		Increased
Swegan (61)	Arm Extending	Practice	Severe	30 sec.	Immediate	No effect

TABLE I (Continued)

Senior Author	Performance Criterion	Type of Warm-Up	Intensity	Duration	Time Lapse	Effect on Speed
Lotter (33)	Arm & shoulder rotating	Related & unrelated	Moderate	2 min.	2 min.	No effect
		Related & unrelated	Moderate	4 min.	2 min.	No effect
Start (59)	Elbow Extension	Practice	Moderate	10 sec.		No effect

TABLE II

SUMMARY OF STUDIES ON THE EFFECTS OF WARM-UP ON ENDURANCE

Senior Author	Performance Criterion	Type of Warm-Up	Intensity	Duration	Time Lapse	Effect on Endurance
Thompson (62)	Swimming	Related & passive heating	Moderate	3-4 min.	5 min.	Increased
		Unrelated	Moderate		5 min.	No effect
Muido (41)	Swimming	Unrelated	Mod.-Sev.	10 min.	20 min.	Increased
		Passive heating	104°-$109^{\circ}F$	18 min.	20 min.	Increased
Mathews (36)	Running	Related	Low mod.		5-10 min.	No effect
Burke (8)	Spot Runn'g	Related	Moderate	2,5,8 min.	5 min.	No effect
		Related	Severe	2,5,10 "	5 min.	No effect
Asmussen (1)	Cycling	Practice	Severe	30 min.		Increased
		Passive heating	$117^{\circ}F$	10 min.		Increased
		Massage		15 min.		No effect
Karpovich (32)	Cycling	Related	Moderate	19 min.		No effect
		Massage		10 min.		No effect
Sedgwick (53)	Hand grip ergometer	Passive heating		5 min.	30 sec.	No effect
Sedgwick (52)		Related	Moderate	9 min.	15 sec.	No effect
Grose (21)	Hand grip ergometer	Massage		4 min.	30 sec.	No effect
		Passive heating	$118^{\circ}F$	8 min.	30 sec.	Decreased
		Passive cooling	$50^{\circ}F$	8 min.	30 sec.	Decreased

nature of the definition, is a very subjective type of classification in which the reported levels cannot be considered completely autonomous. In a number of studies the author failed to report the duration or time lapse and consequently the tables are not complete.

Table III summarizes the studies reported in Tables I and II and includes the results of investigations using performance criteria other than speed and endurance. The category entitled, "Strength and Power," includes the following performance criteria: direct measures of strength (8,53,59), vertical jump (37,44,45,60), and softball or baseball throw (38,49,55,63). The activities listed under the heading, "Others," are accuracy as measured by basketball free shooting (55,60,62), accuracy as measured by shuffleboard skill (8), and general ability as measured by Scott's Motor Ability Test (56).

The per cent values of Tables II and IV give the per cent of studies, using that specific type of warm-up, which resulted in the particular change in performance under which heading the figure is listed. The bracketed figure gives the total number of studies reporting this result. For example, in Table II, of all the studies reported in which speed of movement was the performance tested and a related warm-up preceded it, 17 per cent, or one out of six, of the studies showed warm-up improved speed. No change in speed was noted in 83 per cent or five out of six of these studies. There were no reported studies in which a related warm-up was detrimental to speed of movement. Some studies could not be classified accurately according to intensity and/or duration and therefore the totals of Table IV do not correspond to the total number of studies reported in Table III.

TABLE III

SUMMARY OF WARM-UP EFFECTS AS CITED IN THE LITERATURE

Criterion	Type of Warm-Up	Improved Performance	No Change in Performance	Detrimental to Performance
Speed	Related	17% (1)	83% (5)	
	Unrelated	40% (2)	60% (3)	
	Practice	29% (2)	57% (4)	14% (1)
	Passive	43% (3)	57% (4)	
	All types	32% (8/25)	64% (16/25)	4% (1/25)
Endurance	Related		100% (5)	
	Unrelated	50% (1)	50% (1)	
	Practice	100% (1)		
	Passive	29% (2)	57% (4)	14% (1)
	All types	27% (4/15)	67% (10/15)	7% (1/15)
Strength and Power	Related	100% (3)		
	Unrelated	50% (2)	50% (2)	
	Practice	50% (2)	50% (2)	
	Passive	33% (1)	33% (1)	33% (1)
	All types	57% (8/14)	36% (5/14)	7% (1/14)
Others	Related	100% (1)		
	Unrelated	50% (1)	50% (1)	
	Practice	50% (1)	50% (1)	
	Passive	--	--	
	All types	60% (3/5)	40% (2/5)	0 (0)
Totals		39% (23/59)	56% (33/59)	5% (3/59)

TABLE IV

SUMMARY OF EFFECTS OF VARYING INTENSITIES AND DURATIONS OF WARM-UP ON SPEED AND ENDURANCE

Variable		Improved	Decreased or No Effect
Intensity:	Severe	26% (4)	64% (7)
	Moderate	29% (5)	71% (12)
Duration:	$<$ 5 minutes	21% (3)	79% (11)
	$\geq$ 5 minutes but $<$ 10 minutes	21% (3)	79% (11)
	$\geq$ 10 minutes	64% (9)	36% (5)

The preceding tables make it apparent that the question of the effects of warm-up on athletic performance cannot be resolved from the studies done to this date. Another factor which confounds the issue further still is that many of the cited studies can be criticized for lack of experimental controls and faulty statistical procedures. In cases where the warm-up was a practice session (1,10,32,55,61) it is difficult to ascertain how much of the improvement in performance was due to warm-up as such and how much was due to learning by practice. In other studies (12,45,60), in which the subjects were allowed to warm-up at their own speed, the reliability of the results can certainly be questioned. In a few studies (1,41) there were no statistics applied at all, and in other studies (60,61), the author analyzed his results by using twenty or thirty repeated "t" tests and thereby inflated his reported probability level to a very marked degree.

Velocity and Acceleration

One of the first published studies on warm-up, but still one of the most often cited in the present literature, is the work of Asmussen and Bøje on the effect of increased body temperature on work capacity (1). In their study, four subjects warmed-up by pedalling a bicycle ergometer for thirty minutes at a work load of 660 mkg per minute, and then were tested on the time taken to complete 35 pedal revolutions at maximum speed. The results showed an improvement of 3.5 per cent to 8.0 per cent in the subjects' times over the same test without warming-up. Warming-up by hot showers and by diathermic heating resulted in average increases of approximately five per cent, but fifteen minutes of

massage showed no significant improvement. Further analysis on the 30-minute cycling warm-up showed that a five minute warm-up caused a five per cent improvement but thirty minutes of similar preliminary activity resulted in only a further improvement of three per cent. However, this phase of the experiment was conducted on two subjects only, and consequently no further inferences can be drawn from these results. The aspect of this study which contributes most to the field of knowledge, and an aspect which requires much further investigation, is the reported measurements of deep muscle temperature. This will be discussed in detail in a later section.

Karpovich and Hale (32) performed a similar type of study in which three subjects warmed-up for five minutes cycling at sixty revolutions per minute and then were tested on the same performance criterion as used by Asmussen and Bøje. They report their findings as statistically significant, and the increase in speed, approximately 4.5 per cent, was similar to that found by Asmussen and Bøje.

In neither of these two studies was any mention made of the time lapse between warm-up and test performance. This seems to be a serious omission, especially when considering Asmussen's findings which showed the increase in speed was approximately proportional to the increase in muscle temperature.

Burke (8) conducted a fairly extensive study on the effects of various intensities and durations of warm-up on speed and endurance. His subjects warmed-up by bench stepping at various cadences for varying time intervals, and then were tested on the Carlson Fatigue Curve Test, the highest ten-second score being taken as the measure of speed.

Although there were improvements shown in speed following warm-up they were statistically insignificant and were not nearly of the magnitude of the improvements shown by successive trials on the Carlson Test. Burke therefore concluded that practice effects were overwhelmingly more prominent than warm-up effects in regard to increased speed.

A summary of the five studies on the effects of warm-up on the speed of running (8,10,29,54,57) reveals that only one of the warm-up procedures resulted in an improvement and this was "warm-up" by passive cooling (54). The fact that all four of the studies in which swimming was the performance criterion (9,12,41,62) showed significant increases in speed as a result of at least one of the warm-ups employed seems significant, but this investigator can offer no valid explanation for this phenomenum.

Muscular Endurance

Relatively few of the studies conducted on the effects of warm-up on endurance can be considered as investigations in muscular endurance. Asmussen (1) used a bicycle ride simulating a 1,500 meter run, Karpovich (32) and Mathews (36) a 440 yard run, Thompson (62) a five-minute swim, and Muido (41) a 400 yard swim. In all these situations it is very difficult to differentiate between cardio-respiratory fatigue and localized muscular fatigue from merely studying the literature.

The experiments conducted by Sedgwick (52) and Sedgwick and Whalen (53) are studies directly concerned with the effect of warm-up on muscular endurance. Sedgwick (52) warmed-up his subjects with nine minutes of intermittent finger and wrist exercises, and then tested them

on the maximum number of repetitions they could perform in two minutes on a one-handed grip ergometer. Sedgwick and Whalen (53), working with only three subjects, heated the biceps by the use of short wave radio-diathermy and then tested muscular endurance with a grip hand dynamometer. In neither study was a significant increase in muscular endurance reported.

Burke (8), using the Carlson Fatigue Curve Test as his performance criterion, reported that warm-up had no effect on endurance.

Although the literature indicates that warm-up will not produce any beneficial results in muscular endurance most of the studies can be criticized for failure to control, or investigate, the time lapse factor adequately. It seems possible that the warm-up process itself may cause an increase in blood lactate, or some similar effect, in the muscle which may be detrimental to immediate performance. However, if an adequate rest period is alloted these effects may vanish but the beneficial effects of the warm-up may persist (as shown by the only slight drop in muscle temperature ten minutes after warm-up (53). This hypothesis is mere speculation but it should have been investigated in these studies.

Intensity of Warm-Up

The physiological demands on an athlete caused by warm-up activities are determined by two factors, namely, the intensity and the duration. Some athletes seem to prefer relatively mild preliminary activities such as loose jogging and stretching exercises which they perform for one-half hour or more, whereas others prefer the short explosive activity of "wind" sprints and vigorous calisthenics. Still others seem

to employ a combination of these two extremes. G. Dodds, who ran the mile in 4:05.3 in 1948, warmed-up with slow jogging and stretching exercises for one hour before a race (39). R. Kaines, a 4:10 miler in 1950, warmed-up for an hour by interspersing jogging and walking with 50-yard all out sprints (39). In the experimental studies on warm-up the intensities vary from the very low of jogging and walking for five minutes (54) to the very intense such as an all out 50-yard sprint (29).

In most studies there does not seem to be any valid reason for the selection of the particular intensity of warm-up other than that of convenience, consequently it is not known whether it is more advantageous to perform vigorously for a short duration or moderately for a longer period of time. Burke (8) investigated this by using three different cadences of bench stepping for three different durations of time, but the results as measured by the Carlson Fatigue Curve Test showed no significant differences. However, Burke did not vary the time lapse between warm-up and activity, and so any advantage due to the severe intensity may have been lost due to insufficient recovery time, and any advantages gained due to the low intensity may have been lost as a result of too long a rest period.

Table IV shows that warm-ups of severe and moderate intensities seemed to result in approximately the same percentage of improved performances. Because of the different durations and types of warm-up to which these intensities were applied the slightly greater percentage of beneficial results (36 per cent to 29 per cent) of severe intensity over moderate intensity cannot be considered significant.

Duration

Asmussen and Bøje (1) found that performance in speed and endurance reached a maximum following ten to fifteen minutes of warm-up and that a further fifteen minutes of warm-up resulted in very little further improvement. Burke's (9) investigations revealed that an eight-minute warm-up at a severe intensity resulted in a significant improvement in strength, but not in speed or endurance, over two and five minute warm-ups at a similar intensity. All other investigators failed to examine more than one duration of warm-up--a serious oversight in the opinion of this investigator.

Table IV shows that of the twenty-eight studies in which the duration of the warm-up was less than ten minutes, 21 per cent resulted in an improvement in speed or endurance, whereas of the fourteen studies involving a warm-up of duration ten minutes or more, 64 per cent resulted in an improvement in performance. Although these two groups of studies were not based on the same type or intensity of warm-up the results seem to suggest that a warm-up of at least ten minutes is more likely to be beneficial to performance than one of lesser duration. It is interesting to note that twenty-eight of the forty-two investigations on the effect of warm-up on speed and endurance reported in the literature involved a warm-up period of less than ten minutes. Seeing as most athletes warm-up for a considerably longer time than this (Miller (39) reported that twenty-nine out of thirty-three track and field athletes warmed-up for at least ten minutes) it would seem necessary for an investigation on warm-up to include at least one duration of ten minutes or more.

Time Lapse

Warm-up, if it is to be of benefit to subsequent performance, must precede this performance by a period of time which allows recovery from any fatigue induced by the warm-up and yet is not of such duration as to allow full recovery of the bodily functions to their initial state of rest. It would seem that there should be an optimal length of time to allow for recovery and yet retain any beneficial effects brought about by the warm-up. The fact that most investigators in the area of warm-up have failed to consider time lapse as an important factor is revealed in Tables I and II, which show that less than 50 per cent of the studies even mention it, and none have reported more than one level of time lapse.

DeVries (12), Skubic (55), Carlson (10) and Swegan (61) had their subjects perform the performance criterion immediately following the warm-up. This procedure seems unrealistic in the practical situation where athletes must always wait at least a minute or two after warm-up before the contest begins. Of the eight experimental situations reported in which the activity immediately followed warm-up, only the eight minute related warm-up by DeVries resulted in an increase in performance. Miller (39), in interviewing over thirty top American track and field athletes, found that the majority of them advocated a five to ten minute rest (or at least a greatly reduced activity) before their event, but he states that Costa Holmer, the Swedish Olympic track and field coach, advocates no rest at all between warm-up and performance for sprinters.

Muido (41) warmed his subjects for eighteen minutes in a 40° - 43° C hot bath, and then rested them until their pulse returned to normal

(fifteen to twenty minutes). The performance test, swimming speed and endurance as measured by a 50-yard crawl and a 400-yard crawl respectively, showed an improvement of two to four per cent over the control group. DeVries' (12) subjects warmed-up for six minutes in a hot shower and then were tested immediately in a 100-yard sprint swim, but their times were no better than the control group. One cannot compare these two studies though and conclude that the longer rest period caused the improvement in Muido's studies as it could equally well have been due to the longer duration of warm-up, or that hot baths are better than hot showers, or even that warm-up improves speed over 50 yards but not over 100 yards.

Psychological Effects

Starts' statement (58:284) that, "While the psychologic and physiologic effect of warm-up on the level of performance may be profound. . . ," seems to be an indication of the general assumption that warm-up improves performance through psychological means. Smith and Bozymowski (56) determined the attitude of college women towards warm-up by a questionnaire, and then tested performance with and without warm-up on the obstacle race from Scott's Motor Ability Test. They found that the subjects with a more favorable attitude towards warm-up performed significantly better on the obstacle race when it was preceded by a warm-up than when no warm-up was given, whereas subjects with a less favorable attitude towards warm-up did not show improvement following warm-up. Rochelle et al. (49) tested subjects on the softball throw for distance following a five minute warm-up and then retested them the

following day without warm-up, but offered a monetary reward if they could exceed the previous day's best throw. Despite the incentive given on the no warm-up test period, the softball throws following warm-up were significantly longer than those without warm-up. The value of the incentive can be questioned in this study because of the fairly high degree of incentive induced by competition among the forty-six subjects. It is unlikely that a small monetary reward to university freshmen would be much more of an inducement to maximum performance than within-class rivalry.

Physiological Effects

Is warm-up, as the term is generally used in physical education, a preliminary activity which actually causes an increase in the temperature of certain body tissues? If so, then what tissues are warmed the most and what beneficial effects on performance result from the increased temperature of the particular body parts? These questions will not be investigated in the study but they are questions which need answers if science is to develop a full understanding of warm-up and its effects on subsequent performance. It is generally agreed upon by both physiologists and physical educators that warm-up produces physiological changes in the body which are beneficial to athletic performance. But exactly what these changes are, how they come about, and to what degree each of them benefit performance is not generally agreed upon.

Burke (8) says that his evidence substantiates the theory which states that warm-up causes an increase in the speed of anaerobic energy-yielding chemical reactions within the muscle cells.

Miller (39) quotes a number of track athletes as saying warm-up is a "physiologic necessity." He believes that warm-up, as well as increasing muscle temperature, increases the rate of circulation and therefore the oxygen supply is increased and the rate of carbon dioxide and lactate acid removal is increased.

Muido (41) believes that an increase in blood temperature is more important than an increase in muscle temperature and that this higher temperature causes an increase in the "velocity of reaction." If one considers rectal temperature to be an indication of blood temperature then Carlile (9) contradicts Muido when he states that performance is not closely related to rectal temperature.

Thompson (62) feels that the sole purpose of warm-up is to increase muscle temperature, in fact he defines informal warm-up as "general free movements undertaken solely for raising the temperature of muscles."

DeVries (12) suggests the reasons for warm-up to be: (1) a shortening of the length of the muscle relaxation period, (2) an improvement in muscle tone, and (3) benefit of the treppe effect.

Asmussen and Bøje (1) are some of the few authors who are able to back up their statements on the physiological effects of warm-up with empirical findings. They found that a five minute warm-up increased muscle temperature approximately 1.5°C, rectal temperature approximately five per cent. However, a further twenty-five minutes of warm-up resulted in a further increase in muscle temperature of less than 1.0°C, of rectal temperature of 0.7°C, and of performance three per cent. From this they concluded that an increase in muscle temperature is the

most important purpose of warm-up. They contend that a temperature increase is the most beneficial effect and that circulatory and respiratory adjustment may be left out of consideration. Asmussen and Bøje suggest that the increase in muscle temperature results in a decrease in viscosity and therefore less energy is used in overcoming viscous resistance in swift moving muscles. They also contend that it may accelerate the chemical processes of libertation of energy into the muscles.

Sedgwick (52) believes that it is the initial muscle temperature which is of prime importance, and that optimal muscle temperature is specific to particular muscular activities.

Karpovich, after examining the empirical evidence on the effects of warm-up as reported up to 1958, came to the following conclusion (31:19):

> It is hard to accept facts when they contradict traditional beliefs, but one cannot escape the conclusion that, for short distances, warming-up is probably nothing more than a ritual. Maybe the same is true for long distances. We have no proof that warm-up is beneficial in the endurance-type of exercise.

The limiting factor in the speed of muscular contraction as suggested in many of the current articles on warm-up and exercise physiology texts is muscular viscosity (1,2,8,35,40,56,59). In his early writings Hill (26) often referred to the viscosity of a muscle and in 1928 Fursuawa and Hill stated that (18:41), "The 'viscosity' of the muscles is the chief factor regulating the speed of movement." Riedman remarks that (48:51): "During the warm-up prior to strenuous activity, the slight rise in the temperature of active muscles may increase the effectiveness of contraction by decreasing the viscosity."

It is odd that authors in this decade are attributing an increase in velocity of contraction to a decrease in muscle viscosity when Fenn, et al. (16) were questioning this phenomenon thirty-five years ago, and in 1935 (17) he showed empirically that the speed of shortening was limited by a chemical delay rather than the mechanical delay of friction due to viscosity. In 1950 Hill gave an appropriate epilogue to this theory (27:418):

> The viscous-elastic theory of the active muscle had served its purpose for a long time, it had provoked a variety of new and valuable experiments, but now it must be allowed to die an honorable death.

In the last few years there has been a phenomenal amount of investigation into the mechanics and processes of muscular contraction, thereby making it possible to examine some of the theories of warm-up in the light of recent evidence.

The structure of a striated muscle and the dynamics of its contraction as outlined below are agreed upon by most physiologists today. A muscle fibre is composed of A and I bands--the A bands containing an ordered array of filaments containing 200-400 myosin molecules per fibre with each filament continuing from one end of the A-band to the other. The I-band is composed of thinner filaments containing actin which extend on either side of the Z-line (the mid-line of the I-band), through the I-bands and interdigitate with the myosin fibrils, terminating at the edges of the H-zone in the center of the A-band. Numerous cross bridges extend between the two filaments in the region of overlap. The manner in which the nerve impulse, which sets up a depolarization wave along the sarcolemma of the muscle fibre, instigates the

mechanical process of contraction is not known and there are a number of different theories (3,46,50). The actual contraction itself is achieved by the "crawling action" of the small cross bridges of the actin fibrils which causes the actin and myosin fibres to slide together and overlap (23,40). There is still controversy on this point as some physiologists (19) feel that contraction is brought about by an actual shortening of the A and I bands themselves.

The problem pertinent to this particular paper is, "What causes this contraction process to speed up or slow down with a change in temperature?" Hill (28:165) contends that:

> The intrinsic speed of muscle is inherent in the muscle itself, it depends on physical-chemical factors in its structure and mechanism, not mainly on control by the nervous system--though that also is adjusted to the animal's requirements.

With this in mind and recalling that the muscular contraction necessary to move a limb is actually a great number of contractions one after another resulting in the treppe effect, many of the theories as put forth by investigators on the reasons for warm-up are certainly not justifiable. The presence of the treppe effect makes it very unlikely that a decrease in the relaxation time would increase limb speed. The fact that the latent period is only about two milliseconds and the diffusion time .5 milliseconds, as compared to the contraction time of 30 milliseconds, indicates that a reduction in the duration of the latent period or a speeding up of the chemical processes initiating contraction would have very little effect on the speed of movement.

The only way by which increased temperature would seem to improve the speed of contraction is in the actual contraction process itself.

Unfortunately at this point one arrives at an impasse due to the conflicting evidence between the clinical findings on an isolated muscle and the experimental findings on the exercising subject. Hill (28) states that a muscular contraction could be quickened by about 20 per cent by raising its temperature 2.0°C, and yet Asmussen (1), who raised the muscle temperature in an exercising subject almost 3.0°C, found a subsequent performance improvement in speed of movement of only five per cent. Muido (41) found no improvement in performance after raising the muscle temperature by approximately 1.2°C. The reason for these discrepancies probably lies in the fact that man's body is designed for optimal efficiency and work output, and the contraction speed of a muscle for the optimal condition is 20-30 per cent of its intrinsic speed. If the speed is too high then the auxiliary tissues, bones and tendons cannot withstand the force and break or rupture. It therefore seems that there are some other factors which act as governors to prevent the speed of muscular contraction from exceeding the limits of safety.

In summary, the literature reveals that speed of contraction is probably restricted only by the load imposed upon it and by the temperature of the muscle itself. However, the speed of limb movement does not seem to correlate very highly with the theoretical speed of muscular contraction and therefore the athlete must not only increase his muscle temperature but, if possible, make the necessary adjustments, whatever they may be, to allow for maximum limb speed while staying within the levels of safety.

CHAPTER III

METHODS AND PROCEDURES

Subjects

The sample used in this study consisted of sixty-six Boy Scouts from the Edmonton Boy Scout Association. The subjects were volunteers, between the ages of twelve and fourteen years inclusive. Volunteers with obvious physical defects and those with experience in treadmill running were not permitted to participate in the study. Three subjects were randomly assigned to each of the eighteen treatment conditions and twelve to the control group by a table of random numbers (15).

Time and Duration of the Study

All testing was performed from 4:00 P.M. to 6:00 P.M. and 7:00 P.M. to 9:00 P.M. during the three-week period May 10th to June 4th in the Fitness Research Institute at the University of Alberta, Edmonton.

Materials

The materials and equipment used in this study were: (1) a Quinton Motor-driven treadmill; (2) a Monark bicycle ergometer; (3) an Electronics for Medicine Recorder; and (4) an electric counter and (5) a stop watch.

Experimental Design

A 3 x 3 x 2 factorial experiment with a randomized groups design was used with three observations per cell, thus requiring a total of

fifty-four subjects for the eighteen experimental conditions. A single control group was incorporated containing twelve subjects. This type of design was chosen because it enables one to examine all possible interaction effects and to investigate the effects of numerous treatment conditions while maintaining a relatively small sample size.

The treatment conditions were various types of warm-up as described below, and the dependent variables were measures of acceleration, maximum velocity, and muscular endurance as previously defined. The warm-up was conducted on a treadmill so it would be related to the performance criterion of bicycle pedalling but would not involve the practice effects which might have been introduced if the subjects had warmed-up on the bicycle. The warm-up factors and levels of each factor are as follows:

I: Intensity of Warm-up.	I_1 - Moderate.	Treadmill walking at 4 mph with 0 per cent grade.
	I_2 - Severe.	Treadmill running at 6 mph with 0 per cent grade.
D: Duration of Warm-Up.	D_1 - one minute	
	D_2 - six minutes	
	D_3 - eleven minutes	
T: Time Lapse.	T_1 - one minute	
	T_2 - six minutes	
	T_3 - eleven minutes	

Each treatment condition had three subjects randomly assigned to it, and each subject was tested only once and under only one warm-up condition. The twelve subjects in the control group rested in a sitting position for twelve minutes before performing the bicycle ride. Figure 1

gives a schematic diagram of the experimental design.

Justification of Levels of Independent Variables

In chapters one and two of this thesis, reference was made to the wide variation of warm-up intensities and durations used in previous studies. The levels of each factor in this study were chosen in an attempt to encompass the full range of beneficial levels of these warm-up procedures.

The moderate level of treatment factor I was selected as treadmill walking at four miles per hour because it was felt that this was fairly similar to the various procedures used by other experimenters which were classified as moderate by this investigator. The severe level of treadmill running was chosen as six miles per hour because preliminary investigations showed that this was the fastest speed which could be maintained by 12-14 year old boys for eleven minutes as required in level D_3.

The durations of one, six, and eleven minutes were chosen because it was believed that they would include the full range of beneficial durations at the intensities used. Table IV in Chapter II of this thesis shows that the optimal time allotment for improving performance in previous studies was greater than or equal to ten minutes.

The similar time periods of one, six, and eleven minutes used for the time lapse were considered representative of the situation in many athletic competitions. Some athletes warm-up vigorously until right before their event while others, noticeably football and basketball players, warm-up and then sit on the bench for over ten minutes before

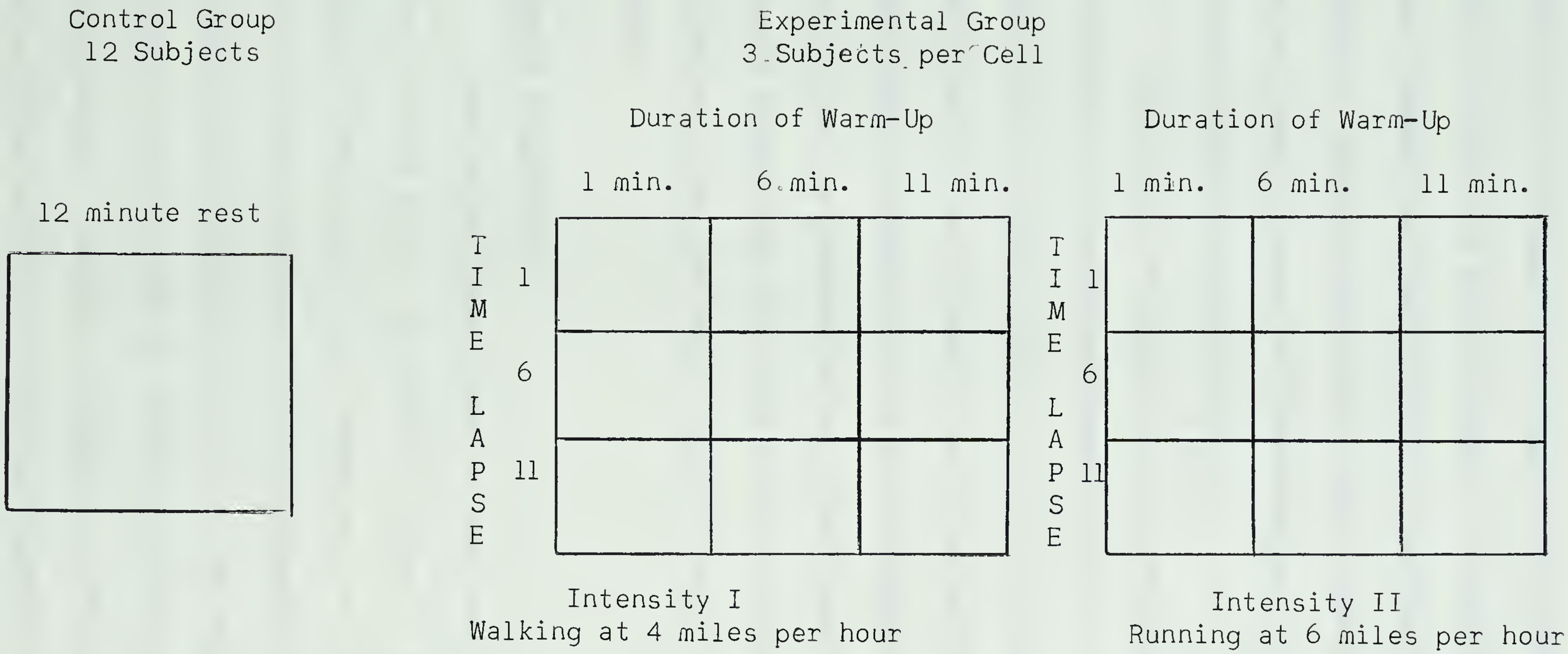

Figure I: Schematic Diagram of Experimental Design

getting into the game. The reason for using six minutes as the second level of factors D and T was that it provided an ordered sequence of time intervals and consequently lended the data available for trend analysis. Twelve minutes was chosen as the length of rest for the control group in order for these subjects to have more rest than the minimum exercise condition $I_1D_1T_3$.

Obviously the ideal situation would be to examine the effects of intensity, duration and time lapse for fifteen or twenty levels of each factor but this is not practical or possible. It is quite possible that a duration of greater than eleven minutes would produce the greatest improvements, however, this was investigated by examination of the results and the presence of any significant linear trends in the main effects showed that the third level of the factor may have been a conservative choice and that a longer duration might give more beneficial results.

Warm-Up Procedures

The subjects were asked to wear shorts, a T-shirt and running shoes for the test. The subject rested in a sitting position for five minutes after entering the laboratory, during which time the experimental procedures pertinent to the treatment condition to which he had been assigned were explained to him. If the subject was assigned to the control condition then he remained sitting for the required twelve minute period. Subjects assigned to levels I_1 and I_2 were given brief instructions on the most efficient manner to run on the treadmill before commencing the activity. Subjects undergoing level I_1, with the treadmill

speed set at four miles per hour, were allowed to walk or jog--whichever they felt most comfortable doing.

Subjects warming-up on the treadmill set at six miles per hour (level I_2) who could not continue at this speed for the full eleven minutes were urged to continue running at a reduced speed. It is the opinion of this investigator that any subject who was too fatigued to complete the full eleven minutes at six miles per hour but managed to continue running for the required time had reached the desired level of exhaustion for the purposes of this study. If a subject could not continue exercising for the full eleven minutes, or could not keep up the six mile per hour pace for the six minutes duration of level D_2, he was dropped from the study and replaced by another subject.

On completion of the warm-up the subjects of levels T_2 and T_3 sat down to rest but subjects under level T_1 immediately moved to the bicycle. The one-minute of sitting on the bicycle was essential in order to fit the toe clips, adjust the seat height so the leg formed an angle of 115^o at the knee when the pedals were in a vertical position, and give the subject the necessary instructions.

<u>Test Procedures</u>

The work load on the Monark bicycle was set at a dial reading of "6", which is a work load of 770 kpm per minute for a pedalling rate of 50 rpm., but 1,540 - 2,700 kpm per minute for the twenty-five second ride at the speed of 100 - 175 rpm., attained by the subjects in this study. Preliminary investigations revealed that lighter work loads caused the subject to encounter difficulty in maintaining contact with

the pedals, and a greater resistance caused difficulty in commencing pedalling. The bicycle was connected to the electric counter which was connected to the Recorder. The paper speed was 50 mm. per second and was marked by the Recorder every one-tenth of a second, as was the completion of every pedal revolution.

On completion of his warm-up and one, six, or eleven minute rest, the subject, while sitting on the bicycle, was given explicit instructions as to what he was required to do (see Appendix A). He was told that on seeing the visual starting stimulus he was to pedal as fast as he could until told by the investigator to stop. The starting stimulus consisted of the sudden jump of a moving dot of light on the oscilloscope of the Electronic Recorder, the exact time of the stimulus being registered on the recording paper. The commencement stimulus was given at the exact time as determined by the particular level of treatment under which the subject was being tested. The recording paper was turned on a few seconds before the starting stimulus; the command, "Ready," given and then the starting signal given. The subject then pedalled as fast as possible for the required length of time while maintaining a sitting position on the bike. At fifteen seconds the command, "Keep it up," was given and then continuous encouragement was given from twenty seconds until the completion of the test. Although the actual time of the test ride was only twenty-five seconds, the subject was not told to stop until twenty-six seconds to be sure that he performed at his maximum for the full twenty-five seconds. The exact twenty-five second period was calculated from the recording paper.

The time of twenty-five seconds was chosen because it would

approximately parallel the effort required for a 220-yard dash and give a measure of muscular endurance. A study by Dickenson (13) showed that maximum velocity was attained in approximately four seconds and began to decrease steadily after ten seconds. It was consequently assumed that the twenty-five second ride of this study would provide an adequate time interval in which to record acceleration, velocity, and muscular endurance.

Experimental Controls

1. All testing was conducted in the late afternoon and early evening and subjects were requested not to participate in any strenuous activity prior to testing.

2. To minimize any psychological effects the subjects were not informed of the nature of the study but were told that the investigation was to determine physiological response to various forms of exercise.

3. Each subject was given a standardized set of verbal instructions (Appendix A) before commencing exercise on the bicycle. Verbal encouragement was given fifteen seconds after pedalling began and continuous encouragement was given for the last five seconds of cycling.

Determination of Dependent Variables

The number of pedal revolutions was computed from the recording paper for every second of the twenty-five second ride, and the maximum number of revolutions completed during any one full second interval was taken as the measure of maximum velocity. The total number of revolutions completed was calculated and used as the measure of muscular endurance, and the time required to pedal four revolutions after completion of the first one (thereby eliminating the reaction time factor)

gave a score for the variable defined as acceleration.

Validity of Dependent Variables

To determine whether the results of the twenty-five second bicycle ride would detect a difference, if present, in the velocity of muscular contraction, four Edmonton Track Club sprinters performed the test. The results confirmed the validity of the test as the sprinter with the best time over 100 yards attained the fastest acceleration and greatest maximum velocity. The sprinter with the slowest recorded time over 100 yards had the slowest acceleration and smallest maximum velocity.

Statistical Treatment

The scores for each of the three dependent variables were analyzed using an analysis of covariance for non-repeated measures in a three-factor experiment (65:595). Examination of the raw scores showed that each of the three dependent variables was highly correlated with weight and therefore the analysis of covariance was applied instead of the analysis of variance as originally intended. This is a posteriori analysis and seemed justifiable due to the covariate, weight, being completely independent of the treatments.

The main effects and interactions were computed by a standard analysis of covariance technique (65:595). The analysis of covariance for trends was applied to the D and T factors and their interactions by a method of orthogonal comparisons as suggested by O'Neil (43:721). The coefficients used are given in Appendix E.

The control group was compared to the experimental group by a similar method of comparisons with the coefficient "2" given to the sum

of all the treatment scores and "9" the coefficient for the control group sum of scores.

The criterion means for the experimental group were adjusted for the linear trend on weight using the experimental data only. The overall experimental and control means were adjusted on the basis of the linear regression using all the data (65:592).

Any F ratio obtained with a probability of occurrence of .05 or less under the null hypothesis was declared statistically significant. The significant main effects were interpreted in the light of the appropriate significant interactions when present.

CHAPTER IV

RESULTS AND DISCUSSION

Preliminary Discussion

Due to the difficulty in interpreting some of the results of this study it was necessary to examine the design of this experiment for any sources of bias.

The 3 x 3 x 2 design employed enabled the investigation of eighteen different treatment conditions plus a control group while maintaining the relatively small sample size of sixty-six subjects. The use of three subjects per treatment condition was used as it was originally calculated that this many subjects would yield a power of approximately 95 per cent against a wrong decision. This was based on the expected error variance for velocity of 0.17 revolutions per minute as given by Asmussen (1) in a similar study. However, in this study the variance was 0.53 revolutions per minute, thus causing a considerable reduction in power in detecting a difference between groups with the probability of a Type I error set at .05. The lack of significance in some of the trend analyses when there are seemingly meaningful differences could be due to this reduction in power.

The subjects were not a random sample of Edmonton boys but were a select group--namely, volunteers from the Boy Scout Association. It is assumed that these boys are a fairly representative sample of 12 to 14 year old boys in Edmonton.

The random assignment of subjects to treatments was done in an

attempt to remove any bias in assigning the subjects to groups careful experimental controls such as a consistent set of verbal instructions, isolation of the subject while undergoing the bicycle ride, and standardization of procedures, equipment, and examiners, were employed, in an attempt to equate all groups with respect to all variables except the warm-up procedures. Analysis of the personal data collected on the subjects showed that the groups were not homogeneous and differed considerably with respect to age and weight. Because age and weight are fairly accurate measures of physical maturity in this age group, the between-group variability influenced the performance scores to a marked degree. The correlation of age and weight with velocity was .70 and .77 respectively. The correlation between weight and velocity with age partialled out was .62, but the correlation between age and velocity with weight partialled out was only .44. This suggests that the relatively high degree of association between age and velocity was a spurious one based to a large degree on weight.

The problem of the various effects of age and weight on the dependent variables could have been avoided by careful blocking prior to testing. However, this was not done and as post-hoc blocking is a dubious procedure in which the end results are difficult to interpret no form of blocking was applied. An analysis of variance would produce results which, due to the large weight differences between treatment groups, and the high correlation between weight and velocity, were a product of weight differences rather than differences due to treatment conditions. Because of this high correlation, and the fact that there was only one subject that might possibly be classified as obese, the

weight of each subject was considered to be a good measure of his physical maturity. It was therefore decided that an analysis of covariance based on weight as the sole covariate would produce the most accurate and realistic results.

Some confusion arises in the interpreting of the results of this experiment due to the fact that the experimental group was heavier than the control group (106.7 pounds to 101.8 pounds) and yet younger than the control group (13.3 years to 13.6 years). The analysis of covariance, based on the linear regression of velocity with weight, adjusted the means for the differences in weight but this adjustment was in the wrong direction for the age differences. Due to the fairly low (.44) first order correlation of age with velocity with weight partialled out, and the high F ratios obtained between experimental and control groups, it is doubtful if the inclusion of age as a multiple covariate with weight would cause any meaningful changes in the results.

It is necessary that it be kept in mind that the warm-up used in this study is of a very specific nature and any inferences drawn must not go beyond the limits imposed by this specificity. Although steady-pace walking and running on the treadmill is classified as a related warm-up in this experiment, it is certainly a very different action to cycling, and there may be very few beneficial carry-over effects from one activity to the other. It is quite possible that a practice warm-up consisting of preliminary cycling would yield results entirely different from those of a related or unrelated warm-up. It is also possible that a warm-up should be of the same intensity as well as of the same type as the performance activity. There are numerous other

types of warm-up, such as practice, massage, and calisthenics which may produce results which do not agree with those found in this study. It is important that it is recognized that all results, conclusions, and inferences which are drawn from the data of this experiment refer to the specific type of warm-up employed, namely, treadmill walking and running, and cannot be assumed to hold true for other types of warm-up. This specificity also applies to the test performance used, namely a brief, high energy expenditure, highly anaerobic activity, and inferences must not be made about other types of activity.

ACCELERATION

Results

The product-moment correlation between weight and acceleration was calculated at -.80. The results yielded by the analysis of co-variance are summarized in Table V.

The individual scores for each treatment condition are presented in Appendix C. The unadjusted means as well as the means adjusted for weight are presented in Appendix D. The means for the main effects, adjusted on the basis of the regression coefficient between weight and the acceleration raw scores, are presented in Table VI.

Discussion

The term "acceleration" as used in this study does not mean a change in velocity per unit time but is a measure of the time taken to complete the second, third, fourth and fifth revolutions at the beginning of the cycling. The scores are perhaps more a measure of initial

TABLE V

SUMMARY OF ANALYSIS OF COVARIANCE ON ACCELERATION

Source of Variation	df	MS	F
Control vs. Experimental	1	.9930	10.10[a]
I (intensity)	1	.4420	4.50[b]
D (duration)	2	.0055	--
Linear	1	.0020	--
Quadratic	1	.0089	--
T (time lapse)	2	.1536	1.56
Linear	1	.0042	--
Quadratic	1	.3029	3.08
I x D	2	.0318	--
Linear	1	.0075	--
Quadratic	1	.0560	--
I x T	2	.0678	--
Linear	1	.1110	1.13
Quadratic	1	.0247	--
D x T	4	.1010	1.02
Linear (D) x Linear (T)	1	.1418	1.44
Linear (D) x Quadratic (T)	1	.1876	1.91
Quadratic (D) x Linear (T)	1	.0023	--
Quadratic (D) x Quadratic (T)	1	.0833	--
I x D x T	4	.0411	--
Linear (D) x Linear (T)	1	.0693	--
Linear (D) x Quadratic (T)	1	.0442	--
Quadratic (D) x Linear (T)	1	.0164	--
Quadratic (D) x Quadratic (T)	1	.0345	--
Error	46	.0983	
Total	64		

[a]$\underline{p} < .01$.

[b]$\underline{p} < .05$.

TABLE VI

ADJUSTED ACCELERATION MEANS FOR MAIN EFFECTS

Independent Variable		Adjusted Mean (seconds)[a]
Intensity:	4 mph.	2.897
	6 mph.	2.701
Duration:	1 min.	2.812
	6 min.	2.788
	11 min.	2.797
Time Lapse:	1 min.	2.764
	6 min.	2.903
	11 min.	2.730
Experimental		2.816
Control		2.644

[a] The time taken to perform four full pedal revolutions on the bicycle after completion of the first revolution.

velocity than acceleration and therefore should not be carelessly compared with true acceleration scores of other studies.

The greater acceleration achieved by the group warming-up at six miles per hour than those warming-up at four miles per hour makes the significantly greater acceleration of the control group than the experimental group difficult to explain. Considering the control group to be similar to a treatment group at zero minutes duration one would expect a linear or quadratic trend over the four levels of duration--0, 1, 6, and 11 minutes. This is not the case however as there is virtually no difference in the three levels of D. Similarly, the superiority of control over experimental suggests that a longer rest period following warm-up would be more beneficial than one of shorter duration. This is

definitely not the case as shown by the complete absence of any linear trend in T. The fact that I_2 resulted in a significantly faster acceleration rate than I_1 confounds the issue further still. If warm-up is detrimental to this type of performance then it would seem that the longer and more intense the warm-up the greater should be the detriment but this is not so as shown by the greater acceleration being achieved after the severe warm-up of six miles per hour.

Considering only the factor intensity, the results of this study support previous investigations which show a slightly greater (36 per cent to 29 per cent) percentage of studies in which performance was improved using a severe warm-up than a moderate one. Burke (8) is the only other investigator who examined more than one level of intensity and he found no significant differences in speed and endurance between three groups warming-up at different rates of bench stepping.

The findings of this study confirm Burke's (8) statement that various durations of warm-up had no differing effects. This could be due to the rapid increase in muscle temperature in the first minute and then relatively little (in comparison to the amount of fatigue) developed in the next ten minutes. Buchthal _et al._ (7) showed that after one minute of exercise the muscle temperature rose .6°C and after a subsequent one minute of rest the temperature rose to 1.2°C above its original resting state. Three minutes of exercise, with or without rest, caused a 2°C increase and ten minutes only a little less than 3°C.

It can be concluded that for brief, high energy expenditure activities, preliminary exercise for the purpose of warming-up is of no value in improving acceleration. In fact a preliminary rest seems to be

superior to the warm-up of moderate intensity of a four miles per hour walk. The fact that the subjects of the control group were older than the subjects in the experimental groups might have caused the difference between the adjusted control and experimental means to be slightly increased but under no circumstances can it be assumed that warm-up is of any benefit in increasing acceleration in this particular activity.

If a warm-up is performed for reasons other than a physiological change causing improvement in acceleration (for example, psychological reasons, reduction in the possibility of injuries) then it should be one of severe intensity. This is necessary in order to cause the bodily functions to operate at a higher rate than normal and thus bring about the physiological changes necessary to facilitate performance. The duration of this warm-up seems to be irrelevant but as durations of greater than eleven minutes have not been investigated it is suggested that a warm-up not exceed this. Although the differences in acceleration due to the varying item intervals of rest following warm-up were not significant they did indicate that a rest of approximately six minutes is less favorable than one or eleven minutes.

It is the unsubstantiated conclusion that any preliminary activity produces physical and mental fatigue to some degree. As well as causing the observed muscular fatigue the warm-up also caused an easing of the apprehension of the coming activity. The experimental subject felt that he had already done half of his task and had only the part involving the bicycle ride left to do. The control subject was mentally ready to put forth his best in this one and only activity. This is an unrealistic situation and quite different from the practical condition

in which the warm-up is only a regular routine before the "big event."

VELOCITY

Results

The product-moment correlation between weight and velocity for the sixty-six subjects tested was .77. The analysis of covariance using weight as the covariate was applied to the mean velocities for the independent variables. The results of the analysis are summarized in Table VII.

The individual scores for each treatment condition are presented in Appendix D. The unadjusted velocity means as well as the velocity means adjusted for weight are presented in Appendix C. The means, adjusted on the basis of the regression coefficient between weight and the velocity raw scores, are presented in Table VIII.

Discussion

The average effect of all types of warm-up compared to the effect of a preliminary rest period on the maximum attainable velocity is similar to that on acceleration--that is, a significant superiority of control over experimental. As with acceleration, the only other significant finding was that a six miles per hour warm-up resulted in a greater velocity than a four miles per hour warm-up. The possible reasons for this are the same as for acceleration and as they were discussed in the previous section of this chapter, they will not be repeated here.

The effect of the duration of warm-up on velocity, although not

TABLE VII

SUMMARY OF ANALYSIS OF COVARIANCE ON VELOCITY

Source of Variation	df	MS	F
Control vs. Experimental	1	.5757	10.94[a]
I (intensity)	1	.4871	9.26[b]
D (duration)	2	.0947	1.80
Linear	1	.0213	--
Quadratic	1	.1682	3.20
T (time lapse)	2	.0659	1.25
Linear	1	.0023	--
Quadratic	1	.1294	2.46
I x D	2	.1581	3.01
Linear	1	.1436	2.73
Quadratic	1	.1726	3.28
I x T	2	.0400	--
Linear	1	.0005	--
Quadratic	1	.0795	1.51
D x T	4	.0680	1.29
Linear (D) x Linear (T)	1	.0962	1.83
Linear (D) x Quadratic (T)	1	.0239	--
Quadratic (D) x Linear (T)	1	.0345	--
Quadratic (D) x Quadratic (T)	1	.1174	2.23
I x D x T	4	.0214	--
Linear (D) x Linear (T)	1	.0319	--
Linear (D) x Quadratic (T)	1	.0337	--
Quadratic (D) x Linear (T)	1	.0000	--
Quadratic (D) x Quadratic (T)	1	.0199	--
Error	46	.0526	
Total	64		

[a]$\underline{p} < .01$.

[b]$\underline{p} < .05$.

TABLE VIII

ADJUSTED VELOCITY MEANS FOR MAIN EFFECTS

Independent Variables		Adjusted Mean (rev./sec.)[a]
Intensity:	4 mph.	2.077
	6 mph.	2.275
Duration:	1 min.	2.111
	6 min.	2.257
	11 min.	2.160
Time Lapse:	1 min.	2.219
	6 min.	2.106
	11 min.	2.203
Experimental		2.153
Control		2.284

[a]Maximum number of revolutions completed in any one second interval during the twenty-five second bicycle ride.

statistically significant, seems meaningful and warrants discussion.

The results, as depicted in Figure 2, imply that a warm-up of only one minute is not long enough to produce any substantial increase in muscle temperature whereas a warm-up of duration six or eleven minutes will increase muscle temperature to the point where it will increase the velocity of contraction. It was previously shown that a warm-up of one minute followed by a one minute rest produces an increase in muscle temperature of approximately 1°C, a six minute warm-up might increase the temperature 2-2.5°C, and an eleven minute warm-up nearly 3°C. The results graphed in Figure 2 suggest that the one degree increase caused by one minute of warm-up is not nearly as beneficial in increasing the velocity of contraction as is the further one degree increase caused by

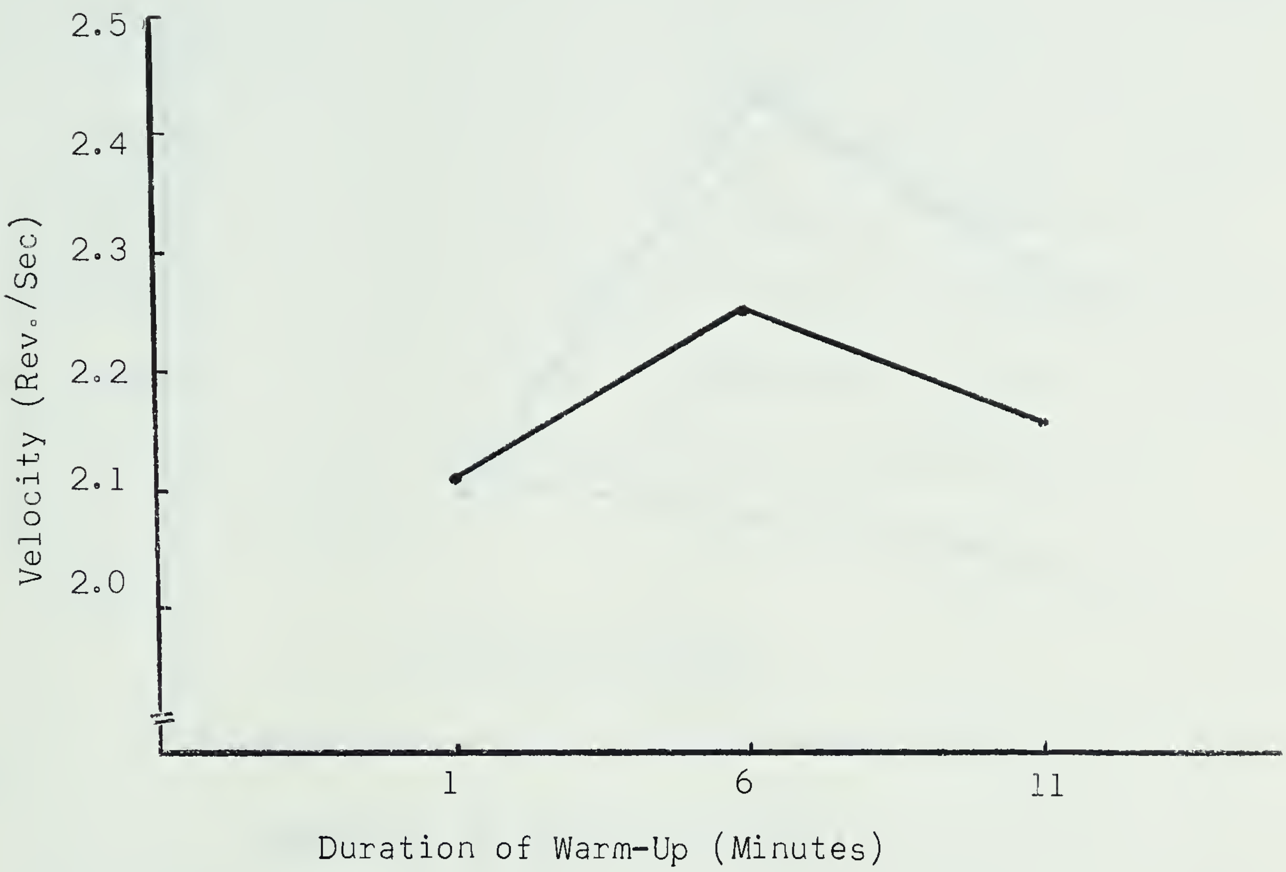

Figure II. Graph of the Mean Velocity for Each Duration of Warm-Up.

the continued five minutes of warm-up. The slight additional increase in muscle temperature resulting from the eleven minutes warm-up is not nearly sufficient to compensate for the increased fatigue caused by this prolonged activity.

The intensity by duration interaction, Figure III, although also not significant (obtained F = 3.01, critical F = 3.20), suggests further evidence in this area.

Figure III points out that all of the quadratic trend in factor D occurs during the six miles per hour warm-up of I_2. At this severe intensity there is considerable improvement in six minutes over one

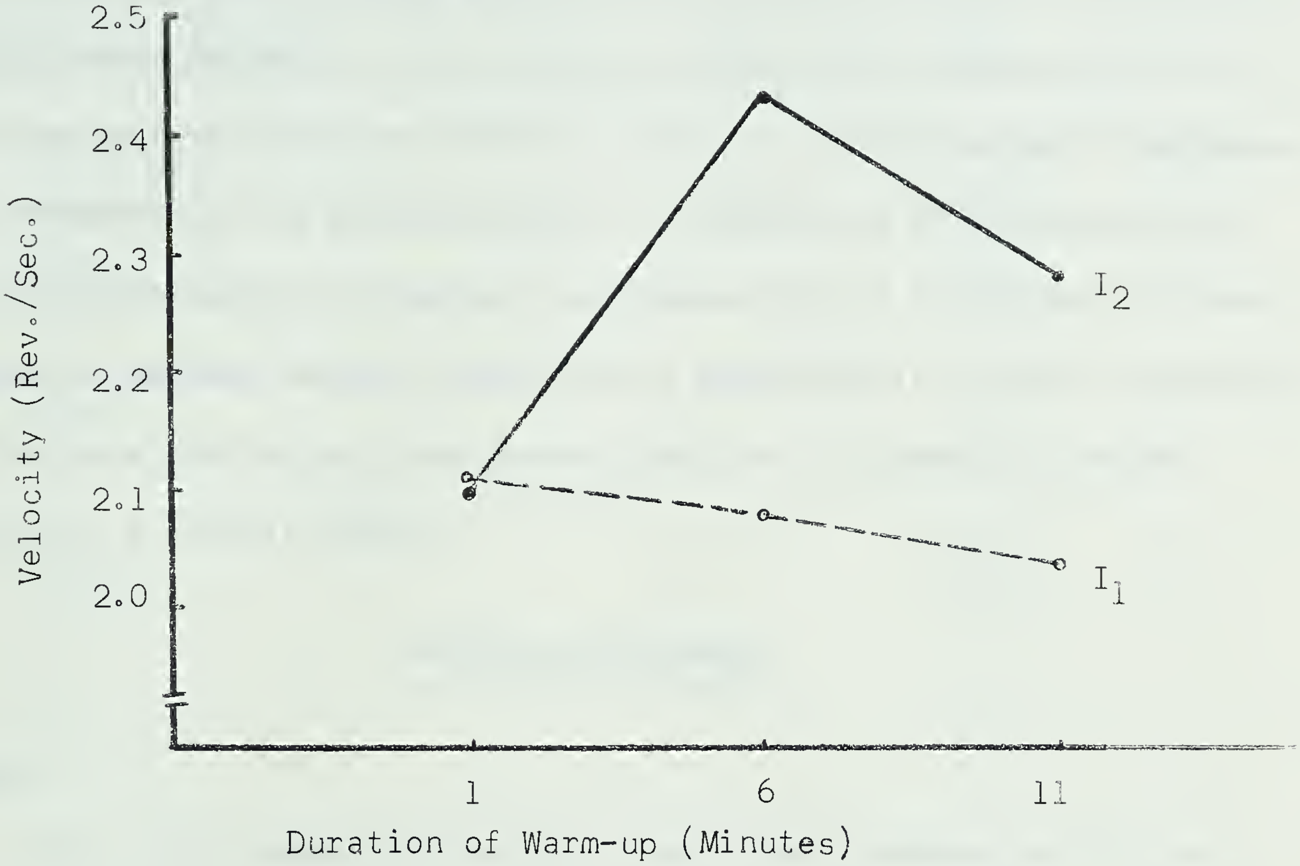

Figure III. Velocity Plotted as a Function of Duration for the Four Miles Per Hour (I_1) and Six Miles Per Hour (I_2) Intensity Conditions.

minute and then as fatigue develops performance drops off at eleven minutes. The moderate warm-up of I_1 is not affected this way by factor D and there is virutally no difference between the three different durations. This is probably due to the very little fatigue produced and relatively constant muscle temperature at the mild warm-up of walking at four miles per hour.

If, for some reason, an athlete wishes to warm-up at a moderately low level of intensity, then a one minute warm-up is just as good as ten minutes as far as performance of this nature is concerned. If,

however, he is warming-up at a fairly severe intensity then he must be careful to perform long enough to increase his muscle temperature sufficiently but not of such duration as to induce fatigue to the point of performance decrement. The results of this study suggest that to attain maximum velocity the optimal length of a six miles per hour warm-up is between one and eleven minutes. A warm-up at this intensity for eleven minutes appears to be much too severe for 12 to 14 year old boys. Although an optimal warm-up condition is suggested it is still decidedly inferior to a preliminary rest period for the attainment of maximum velocity on a bicycle sprint.

MUSCULAR ENDURANCE

Results

The product-moment correlation coefficient between weight and muscular endurance for the sixty-six subjects of this study was .81. The analysis of covariance using weight as the covariate was applied yielding the results summarized in Table IX.

The means were adjusted on the basis of the regression coefficient between weight and the muscular endurance raw scores. The unadjusted means and the adjusted means for each treatment condition are presented in Appendix D, and the adjusted means for the main effects are presented in Table X.

Discussion

The effect of warm-up on muscular endurance as measured in this study is similar to the effect on acceleration and velocity; that is, the

TABLE IX

SUMMARY OF ANALYSIS OF COVARIANCE ON MUSCULAR ENDURANCE

Source of Variation		df	MS	F
Control vs. Experimental		1	394.19	15.86[a]
I (intensity)		1	120.73	4.86[b]
D (duration)		2	28.89	1.16
Linear	1		9.87	--
Quadratic	1		47.90	1.93
T (time lapse)		2	16.22	--
Linear	1		9.27	--
Quadratic	1		23.17	--
I x D		2	40.38	1.62
Linear	1		27.02	1.09
Quadratic	1		53.74	2.16
I x T		2	22.62	--
Linear	1		1.37	--
Quadratic	1		43.86	1.76
D x T		4	41.46	1.67
Linear (D) x Linear (T)	1		68.53	2.76
Linear (D) x Quadratic (T)	1		.76	--
Quadratic (D) x Linear (T)	1		38.12	1.53
Quadratic (D) x Quadratic (T)	1		58.41	2.35
I x D x T		4	4.05	--
Linear (D) x Linear (T)	1		8.48	--
Linear (D) x Quadratic (T)	1		1.92	--
Quadratic (D) x Linear (T)	1		4.74	--
Quadratic (D) x Quadratic (T)	1		1.06	--
Error		46	24.85	
Total		64		

[a]$\underline{p} < .01$.

[b]$\underline{p} < .05$.

TABLE X

ADJUSTED MEANS FOR MUSCULAR ENDURANCE FOR MAIN EFFECTS

Independent Variable		Adjusted Mean (revs.)[a]
Intensity:	4 mph.	42.83
	6 mph.	45.94
Duration:	1 min.	43.17
	6 min.	45.76
	11 min.	44.23
Time Lapse:	1 min.	45.38
	6 min.	43.44
	11 min.	44.34
Experimental		43.95
Control		47.37

[a]The total number of pedal revolutions completed in the twenty-five second ride.

warm-up produces a detrimental effect on muscular endurance and a severe warm-up is superior to a moderate one.

It is strange that the intensity by duration interaction was not significant as the subjects who warmed up for eleven minutes at six miles per hour showed considerable fatigue at the completion of their warm-up, whereas the subjects warming up for eleven minutes at four miles per hour showed very few outward signs of fatigue. The trend, although not significant, was in the opposite direction expected. The nine subjects under condition I_1D_3 averaged 42.52 revolutions compared to the 46.01 revolutions averaged by the subjects performing warm-up condition I_2D_3. This would seem to suggest that the more taxing warm-up produced some change beneficial to muscular endurance. However, the 46.01 average of

the I_2D_3 group was still below the control group mean of 47.37 revolutions, thus suggesting any beneficial change was not great enough to compensate for the decrease in performance due to fatigue or any other detrimental factor.

If an athlete warms-up before a sudden "all-out" type of activity such as a 220-yard dash it is necessary to perform this warm-up at a fairly high intensity in order to maintain a high rate of speed for the full time period. The duration of the warm-up and the length of the rest period following warm-up seem to have very little effect on muscular endurance although a warm-up of only one minute is perhaps too brief.

General Discussion

Although many theories on the physiological effects of warm-up exist the one which seemed most appropriate in this case was that of increased muscle temperature. It is generally accepted that exercise will cause an increase in muscle temperature and all studies which have measured deep muscle temperature (1,41,52,53) verify this theory. Studies by Hill (28) show that this increase in muscle temperature will cause a subsequent increase in the velocity of muscular contraction. Other theories do not seem applicable for the type of performance activity employed in this experiment. The improvement in neuro-muscular facilitation would seem to apply to a practice warm-up only, and the theory involving a beneficial adjustment in cardio-respiratory functioning may apply to a prolonged activity but probably not to the brief, anaerobic activity utilized in this study. It has therefore been accepted

that the main benefits which might be derived from a warm-up preceeding a brief, high speed activity are due to an increase in muscle temperature.

This investigation has shown that a warm-up of the nature of the one employed here does not result in an improvement in acceleration, velocity, or muscular endurance as measured by the particular performance criterion of this study. The results also imply that for the specific type of warm-up used the only variable which affects high speed, anaerobic performance is the intensity at which the warm-up is conducted. The results of this study suggest that the duration of the warm-up is of importance only at severe intensities and the difference between one and ten minutes of rest following warm-up is negligible.

There are a number of possible reasons why the control group scores were superior to those of the experimental group on all three dependent variables. It could be that although warm-up produces a beneficial increase in muscle temperature it also causes other physiological changes (such as fatigue) which are detrimental to performance. It is possible that the motivational effect mentioned in the discussion on acceleration caused the control group's superior performance. There is a slight chance that the control group were fundamentally a superior group with respect to the performance criterion and performed better in spite of the lack of warm-up and not because of the absence of any warm-up effects. However, as the probability of drawing such a sample for the control group is less than one in a hundred this investigator is inclined to adopt the former two reasons for the superiority of control over experimental.

The significant difference for all three performance measures (acceleration, velocity and muscular endurance) between four miles per hour and six miles per hour must be due to the greater increase in muscle temperature produced by the more intense warm-up of six miles per hour. The intensity I, is only a brisk walk and probably did not produce any major changes in physiological functioning of the body. However, the six miles per hour warm-up was an activity of fairly severe intensity for 12 to 14 year old boys and probably elicited considerable physiological changes. The muscle temperature increase over that caused by a warm-up of four miles per hour was sufficiently large to produce an increase in the velocity of contraction, thereby causing the better scores in acceleration and velocity, and, to some extent, the improvement in muscular endurance.

Because the effects of different durations were averaged over both intensities they did not produce any statistically significant differences. The four mile per hour warm-up did not cause a sufficient change in muscle temperature regardless of the duration. Those subjects warming-up at six miles per hour for six minutes attained considerably higher scores than those warming-up for one or eleven minutes. This quadratic trend in duration for the six miles per hour warm-up was probably due to the greater increase in muscle temperature, and consequent greater velocity of muscular contraction, attained by the six minutes of exercise than that attained by the one minute warm-up. The fatigue caused by eleven minutes of warm-up at the severe intensity was of sufficient magnitude to overshadow any benefits gained by a further increase in muscle temperature.

Because the main beneficial effect of warm-up on this type of performance activity is an increase in muscle temperature, the difference between one and eleven minutes of rest following warm-up was negligible. It has been shown (53) that the temperature of a muscle decreases very slowly on cessation of exercise. If the muscle temperature is increased by $5^{o}C$ then fifteen minutes after the warm-up is completed the temperature will still be approximately $4^{o}C$ higher than it was originally. It is therefore probable that the rest period following warm-up would have to be at least twenty minutes to half an hour in order to cause a sufficient decrease in muscle temperature to result in a change in performance.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the effects of various warm-up procedures on acceleration, velocity, and muscular endurance as measured by a twenty-five second ride on a bicycle ergometer. The experimental design was a 3 x 3 x 2 factorial experiment with three subjects randomly assigned to each treatment condition and a single control group consisting of twelve subjects. The sixty-six subjects used were volunteers from the Edmonton Boy Scout Association ranging in age from twelve to fourteen years. The independent variables employed were: intensity of warm-up (four and six miles per hour), duration of warm-up (one, six, and eleven minutes), and length of rest following warm-up (one, six, and eleven minutes). Each subject performed one warm-up condition and then pedalled a bicycle ergometer as fast as he could for twenty-five seconds. The number of revolutions pedalled per second was electrically recorded and measurements of acceleration, velocity, and muscular endurance calculated from this recording.

The conclusions were as follows:

1. For a brief, high-energy expenditure type of activity such as the one employed in this investigation, a warm-up consisting of steady pace running is of no benefit to acceleration, velocity, and muscular endurance.

2. A warm-up at a fairly severe intensity of six miles per hour

produces greater acceleration, velocity, and muscular endurance than one at a moderate intensity of four miles per hour.

3. The duration of warm-up is probably important only at the severe intensity level and it affects only the maximum velocity attainable.

4. The length of the rest period between the warm-up and the performance test has little effect on acceleration, velocity, or muscular endurance.

Recommendations

The methods employed in this study involved a specific type of warm-up, a specific aspect of performance and a specific age group of subjects. Due to this specificity the results of this thesis must not be used to draw inferences concerning other warm-ups and other types of performance. The following areas of investigation are therefore recommended for further study.

1. A similar study should be conducted on subjects older than the twelve to fourteen year olds participating in this investigation. The intensity and duration of the warm-up should be adjusted for more physically mature groups.

2. The results of this study showed that a warm-up at an intensity of six miles per hour was superior to one conducted at four miles per hour. It is recommended that a warm-up of greater intensity, perhaps eight miles per hour, be employed to see if there is an improvement over six miles per hour. Warm-ups of increasing intensity should subsequently be investigated until such time as an increase in speed does

not result in improved performance and the optimal intensity is ascertained.

4. The effects that the warm-up procedures used in this study have on other components of performance such as strength, coordination, and cardio-respiratory endurance during prolonged activity, needs investigation. The effects of warm-up on post activity stiffness, or "tightening up," and the time required for the body to return to the physiological resting state should also be examined.

5. The effect that other types of warm-up such as a practice warm-up or an unrelated warm-up have on all aspects of performance must be investigated.

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APPENDIX A

INSTRUCTIONS TO SUBJECTS

INSTRUCTIONS TO SUBJECTS BEFORE TWENTY-FIVE SECOND BICYCLE RIDE

When you see the stimulus light go on you are to pedal as hard and as fast as you can. I am interested in finding out how quickly you can reach your top speed and how long you can keep it up. After about ten seconds you will start getting tired but just keep going as fast as you can. I will tell you to stop in twenty-five seconds.

APPENDIX B

INDIVIDUAL SCORE SHEET

UNIVERSITY OF ALBERTA

DATA SHEET

NAME ______________________________ DATE __________

ADDRESS ______________________________ TEMP. __________

PHONE ____________________ SCOUT TROOP __________

Available for re-test in: July August Parental Consent _____

Age ______ ______ Height __________ Weight ______________
years months

EXPERIMENTAL CONDITION ____________________

VELOCITY ____________________ TIME ____________

MUSCULAR ENDURANCE ____________________

RESPIRATION		HEART RATE	
1 - 5	________	1 - 5	________
6 - 10	________	6 - 10	________
11 - 15	________	11 - 15	________
16 - 20	________	16 - 20	________
21 - 25	________	21 - 25	________

COMMENTS:

APPENDIX C

INDIVIDUAL ACCELERATION, VELOCITY, AND MUSCULAR ENDURANCE SCORES FOR EACH TREATMENT COMBINATION

INDIVIDUAL SCORES

		Acceleration			Velocity			Muscular Endurance		
D_1	T_1	3.56	2.74	2.70	1.60	2.50	1.95	33.9	49.4	40.0
	T_2	3.06	3.32	2.00	1.75	1.76	2.83	35.8	38.0	59.2
	T_3	3.14	2.45	2.22	1.90	2.42	2.79	38.2	48.2	56.2
I_1D_2	T_1	3.65	3.25	2.20	1.45	2.49	1.85	30.5	43.5	44.0
	T_2	2.67	2.70	2.45	2.00	2.00	2.05	50.6	44.7	58.0
	T_3	3.02	2.48	2.23	2.40	2.93	2.75	40.4	44.6	55.3
D_3	T_1	2.85	3.35	2.38	2.07	1.62	8.84	44.1	34.5	59.0
	T_2	3.90	2.33	2.34	1.37	2.53	2.38	27.0	54.0	53.5
	T_3	3.15	2.73	2.10	2.64	2.11	2.39	34.0	38.8	51.1
D_1	T_1	3.38	3.15	2.96	1.85	1.64	2.47	38.5	35.3	49.6
	T_2	3.15	3.05	3.38	1.75	1.88	2.00	31.4	39.3	40.3
	T_3	2.55	2.80	2.75	2.75	1.45	2.25	35.8	29.5	47.4
I_2D_2	T_1	2.27	3.45	3.16	2.43	2.55	2.31	47.4	51.3	46.4
	T_2	2.60	1.92	2.13	2.92	2.96	2.51	37.2	66.8	53.6
	T_3	2.85	2.18	2.60	2.00	2.73	2.92	36.1	54.4	59.4
D_3	T_1	2.75	4.06	3.10	2.19	2.30	2.28	43.0	47.2	47.4
	T_2	2.75	2.90	2.85	1.54	2.25	2.42	31.5	48.4	47.5
	T_3	2.35	2.15	2.50	1.90	2.17	2.65	35.5	43.3	51.9
Control		3.75	3.20	2.48	1.53	2.62	2.57	49.7	36.2	56.0
		3.36	3.10	2.07	2.42	2.56	2.49	31.6	39.5	49.8
		2.40	2.15	2.50	1.51	1.82	2.86	32.8	53.0	52.4
		3.25	2.50	2.33	1.89	1.67	2.30	36.8	53.4	53.5

APPENDIX D

ADJUSTED AND UNADJUSTED MEANS FOR EACH TREATMENT CONDITION

UNADJUSTED AND ADJUSTED MEANS

Treat-ment		Weight	Acceleration Unadj.	Acceleration Adj.	Velocity Unadj.	Velocity Adj.	Muscular Endurance Unadj.	Muscular Endurance Adj.
D_1	T_1	102.6	3.000	2.918	2.017	2.086	41.10	42.57
	T_2	112.0	2.793	2.908	2.113	2.027	44.33	42.45
	T_3	113.0	2.603	2.781	2.370	2.234	47.53	44.58
I_1D_2	T_1	105.0	3.033	3.071	1.950	1.980	39.33	39.96
	T_2	123.7	2.607	2.966	2.473	2.194	51.10	45.04
	T_3	116.3	2.577	2.782	2.217	2.059	46.77	43.33
D_3	T_1	105.3	2.860	2.834	2.177	2.201	45.87	46.38
	T_2	114.7	2.857	3.027	2.093	1.963	44.83	42.00
	T_3	112.7	2.660	2.788	2.047	1.950	41.30	39.18
D_1	T_1	97.0	3.027	2.826	1.987	2.150	41.13	44.63
	T_2	97.3	3.000	2.806	1.877	2.034	37.00	40.38
	T_3	87.7	3.030	2.633	1.817	2.135	37.57	44.41
I_2D_2	T_1	106.3	2.573	2.569	2.430	2.438	48.37	48.52
	T_2	112.7	2.517	2.645	2.463	2.366	50.87	48.77
	T_3	109.7	2.630	2.895	2.550	2.503	49.97	48.92
D_3	T_1	94.7	2.617	2.367	2.257	2.459	45.87	50.20
	T_2	108.0	3.037	3.067	2.070	2.051	42.47	42.02
	T_3	101.0	2.817	2.700	2.240	2.337	43.57	45.63
Experi-mental Mean		106.7	2.791	2.792	2.175	2.176	44.39	44.39
Control Mean		100.2	2.757	2.644	2.186	2.284	45.39	47.37

APPENDIX E

COEFFICIENTS FOR TREND ANALYSIS

COEFFICIENTS FOR ANALYSIS OF COVARIANCE ON TREND

Treatment	$I_1D_1T_1$	$I_1D_1T_2$	$I_1D_1T_3$	$I_1D_2T_1$	$I_1D_2T_2$	$I_1D_2T_3$	$I_1D_3T_1$	$I_1D_3T_2$	$I_1D_3T_3$
D(lin)	-1	-1	-1	0	0	0	1	1	1
D(quad)	1	1	1	-2	-2	-2	1	1	1
T(lin)	-1	0	1	-1	0	1	-1	0	1
T(quad)	1	-2	1	1	-2	1	1	-2	1
I x D(lin)	1	1	1	0	0	0	-1	-1	-1
I x D(quad)	-1	-1	-1	2	2	2	-1	-1	-1
I x T(lin)	1	0	-1	1	0	-1	1	0	-1
I x T(quad)	-1	2	-1	-1	2	-1	-1	2	-1
D(lin) x T(lin)	1	0	-1	0	0	0	-1	0	1
D(lin) x T(quad)	-1	2	-1	0	0	0	1	-2	1
D(quad) x T(lin)	-1	0	1	2	0	-2	-1	0	1
D(quad) x T(quad)	1	-2	1	-2	4	-2	1	-2	1
I x D(lin) x T(lin)	-1	0	1	0	0	0	1	0	-1
I x D(lin) x T(quad)	1	-2	1	0	0	0	-1	2	-1
I x D(quad) x T(lin)	1	0	-1	-2	0	2	1	0	-1
I x D(quad) x T(quad)	-1	2	-1	2	-4	2	-1	2	-1
	$I_2D_1T_1$	$I_2D_1T_2$	$I_2D_1T_3$	$I_2D_2T_1$	$I_2D_2T_2$	$I_2D_2T_3$	$I_2D_3T_1$	$I_2D_3T_2$	$I_2D_3T_3$
D(lin)	-1	-1	-1	0	0	0	1	1	1
D(quad)	1	1	1	-2	-2	-2	1	1	1
T(lin)	-1	0	1	-1	0	1	-1	0	1
T(quad)	1	-2	1	1	-2	1	1	-2	1
I x D(lin)	-1	-1	-1	0	0	0	1	1	1
I x D(quad)	1	1	1	-2	-2	-2	1	1	1
I x T(lin)	-1	0	1	-1	0	1	-1	0	1
I x T(quad)	1	-2	1	1	-2	1	1	-2	1
D(lin) x T(lin)	1	0	-1	0	0	0	-1	0	1
D(lin) x T(quad)	-1	2	-1	0	0	0	1	-2	1
D(quad) x T(lin)	-1	0	1	2	0	-2	-1	0	1
D(quad) x T(quad)	1	-2	1	-2	4	-2	1	-2	1
I x D(lin) x T(lin)	1	0	-1	0	0	0	-1	0	1
I x D(lin) x T(quad)	-1	2	-1	0	0	0	1	-2	1
I x D(quad) x T(lin)	-1	0	1	2	0	-2	-1	0	1
I x D(quad) x T(quad)	1	-2	1	-2	4	-2	1	-2	1